AIRCRAFT ACCIDENT REPORT 3/92

Air Accidents Investigation Branch

Department of Transport

Report on the incident to De Havilland DHC-7, G-BOAW between Brussels Airport and London City Airport on 30 January 1991

This investigation was carried out in accordance with

The Civil Aviation (Investigation of Air Accidents) Regulations 1989

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Department of Transport
Air Accidents Investigation Branch
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12 June 1992

The Right Honourable John MacGregor
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr D F King an Inspector of Air Accidents, on the circumstances of the incident to De Havilland DHC-7, G-BOAW that occurred between Brussels and London City Airport, on 30 January 1991.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
AD	-	Airworthiness Directive
AFCS	-	Automatic Flight Control System
ATC	-	Air Traffic Control
°C	-	Centigrade (Celsius)
CAA	-	Civil Aviation Authority
CG	-	centre of gravity
CVR	-	Cockpit Voice Recorder
FL	-	flight level
fpm	-	feet per minute
g	-	normal acceleration
hrs	-	hours
IAS	-	Indicated Airspeed
ILS	-	Instrumernt Landing System
kg	-	kilogram(s)
km	-	kilometre(s)
kt	-	knot(s)
mb	-	millibars
QNH	-	Corrected mean sea level pressure
STOL	-	short take-off and landing
TCS	-	Touch Control Steering
UFDR	-	Universal Flight Data Recorder
UTC	-	Coordinated Universal Time
UK	-	United Kingdom

Air Accidents Investigation Branch

Aircraft Accident Report No: 3/92

(EW/C91/1/5)

Registered Owner and Operator:	British Midland Airways
Aircraft Type:	De Havilland Canada DHC-7
Aircraft Model:	Series 110
Nationality:	British
Registration:	G-B0AW
Place of incident:	Between Brussels Airport and London City Airport Latitude: 51° N (approximate) Longitude: 004° E (approximate)
Date and time:	30 January 1991 at 1910 hrs

All times in this report are UTC

Synopsis

The Air Accidents Investigation Branch (AAIB) became aware of the incident during the evening of 30 January 1991 and an investigation commenced early the following day.

The following AAIB personnel participated in the investigation:-

Mr D F King, Principal Inspector of Air Accidents (Engineering)	Investigator in Charge
Mr J D Payling, Senior Inspector of Air Accidents (Operations)	Operations
Mr P R Coombs, Senior Inspector of Air Accidents (Engineering)	Engineering
Mr P F Sheppard, Assistant Principal Inspector of Air Accidents (Engineering)	Flight Recorders

Shortly after a night take-off from Brussels, the aircraft experienced a sudden uncommanded pitch-up. As the flight progressed the crew became aware that a pitch control problem was present in both autopilot and manual controlled flight. An emergency was declared and the aircraft diverted from the London City Airport, its planned Short Take-Off and Landing (STOL) destination airfield, to carry out a successful flapless landing at Stansted, a conventional aerodrome.

The following causal factors were identified:-

(i) Condensation was able to collect in and around the elevator servo-drive drum bracket and freeze causing an elevator control restriction which affected pitch control in both automatic and manual controlled flight.

(ii) Following earlier known cases of water collecting in and around the elevator servo-drive drum bracket no effective modification action was implemented.

(iii) The flight deck crew's ability to discuss and analyse their predicament was impaired by the distraction provided by the continuous operation of the autopilot disconnect warning.

Four Safety Recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of the flight

The aircraft was engaged on a scheduled return passenger service between London City Airport and Brussels. After arriving at Brussels, where the ambient temperature was -1°C, it spent one hour on the ground, during which time some condensation formed on the outside surfaces but no ice was evident. It departed for the return flight at 1900 hrs.

Some 10 minutes after take-off, whilst climbing with the autopilot engaged and vertical speed mode selected to achieve a 600 feet per minute (fpm) climb, the aircraft pitched sharply nose-up and the Indicated Airspeed (IAS) dropped. The Universal Flight Data Recorder (UFDR) showed that as the aircraft was climbing at 600 fpm through 8,000 feet at approximately 175 kt, it pitched up from +3° to +11° and the speed decreased to 162 kt before a normal climb was resumed. This pitch disturbance was preceded by the elevator trim moving steadily in a nose-up direction. The commander did not disengage the autopilot but instead pressed the Touch Control Steering (TCS) button and returned the aircraft to a normal climbing attitude. He considered various possible causes of the pitch-up including, autopilot altitude capture malfunction, an out of trim situation and the movement of passengers and/or hold baggage. He selected elevator de-icing and the cabin attendant was called to check passenger positions and baggage loading. The commander also considered the possibility of wake turbulence but had no evidence of any other aircraft in the vicinity which might have caused it. He also rejected the possibility of airframe icing because the aircraft had not encountered any cloud during the climb out from Brussels.

He continued the climb to his flight plan cruising level of Flight Level (FL)140, where he levelled off and established a normal cruise configuration at 182 kt, clear of cloud and in smooth air. After the initial pitch-up, elevator trim operation appeared to be normal. During the cruise he intermittently engaged and disengaged the autopilot. The commander described a slight resistance in pitch control in manual flight and a tendency to instability in pitch in both autopilot and manual controlled flight. He stated that the elevator control felt 'notchy' and the control column tended to move away from the neutral, trimmed position. Consequently it required particular concentration to hold it in the neutral position. He felt, nevertheless, that he had adequate control of the elevators for continued safe flight.

After some 10 minutes in the cruise at FL140 the commander began an early descent in order to check the handling characteristics at lower altitude. He received clearance to descend to FL80, where he found that the aircraft tended to be slightly more divergent in pitch but was still controllable. He continued to Southend, descending to 5,000 feet where he encountered some stratus cloud, and began an orbit over

Southend whilst he discussed the situation with ground maintenance engineers at his destination. On their advice he disconnected the left/right elevator controls and aircraft handling appeared to be the same on both control channels. The first officer commented that, with the controls split, control of the aircraft in pitch required larger control inputs than those he recalled from training exercises in that configuration. The commander then reconnected the split controls and instructed the first officer to pull the autopilot and yaw damper circuit breakers. This action also had no effect on the apparent abnormal handling characteristics. The commander commented that from that moment on he was distracted by the autopilot warning horn, which sounded continuously until the aircraft was landed and shut down.

He continued the flight to London City STOL Airport, descending to 3,000 feet in preparation for an Instrument Landing System (ILS) approach. When the aircraft was slowed to 140 kt the elevator control still felt notchy, with the control column resisting attempts to hold it in the neutral trim position. At this stage the manual trim wheel appeared to stiffen up. The commander decided to make an early selection of landing gear and flap at 3,000 feet in order to assess any effect this might have on his margin of control. Both the commander and the first officer reported that the nose pitched down sharply when flaps were selected to 15°, leading to the decision to retract them again quickly. The UFDR showed no evidence of this pitch-down and showed that the flaps ran to no more than 5° down before they were reselected up.

The commander then decided that it would be prudent to make a flapless landing and advised Air Traffic Control (ATC) accordingly, declaring an emergency and requesting diversion to the conventional airport at Stansted. He instructed the cabin staff to brief the passengers to prepare for a precautionary landing and to demonstrate the brace position to be adopted if so instructed.

ATC provided radar headings for the aircraft to intercept the Stansted localiser. Shortly before touch-down the commander instructed the passengers to adopt the brace position as a precaution in case of loss of pitch control in the flare. He was, however, able to execute a safe flapless landing on runway 05. He reported that the aircraft became harder to control during the ILS approach, which was flown for the most part using power rather than elevator to control pitch attitude. He also had the impression that the manual trim wheel had become progressively stiffer during the latter part of the flight.

After the landing at Stansted, a group of maintenance personnel from London City Airport travelled to the aircraft where they removed the autopilot computer and controller, the pitch servo-drive and the pitch trim motor. Replacements were installed for the computer, the controller and the servo-drive, but the electrical connection to the servo-drive was left unconnected and the autopilot was isolated by locking out the three relevant autopilot and yaw damper circuit breakers. The trim motor was not replaced. Functional checks of the flying controls were carried out together with an examination of the pitch control circuit.

The aircraft was then flown back to London City Airport. When interviewed subsequently, the pilot who carried out the ferry flight reported that no problems were encountered and that the flight was conducted in a basically normal manner in terms of flap and landing gear operation and speed range used. Only the maximum height reached, and the flight duration, differed from those of a typical revenue flight.

1.2 Injuries to persons

	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor/none	4	29	

1.3 Damage to aircraft

The aircraft was undamaged.

1.4 Other damage

There was no other damage.

1.5 Personnel information

1.5.1	*Commander:*	Male, aged 38 years	
	Licence:	Airline Transport Pilot's Licence	
	Aircraft ratings:	Embraer 110, Piper PA31/23/34, Britten Norman BN2, DHC-7	
	Medical certificate:	Class 1, issued 1 August 1990, valid to 28 February 1991, no limitations	
	Instrument rating:	renewed 27 December 1990	
	Last base check:	27 December 1990	
	Last route check:	29 August 1990	
	Flying experience:	total all types:	4,300 hours
		total on type:	1,500 hours
		total previous 90 days:	57.25 hours
		total previous 28 days:	31.5 hours
	Duty time:	5.6 hours	
	Rest period before duty:	17.2 hours	

1.5.2	*First Officer:*	Male, aged 28 years
	Licence:	Commercial Pilot's Licence
	Aircraft ratings:	Cessna 150 and 310, DHC-7
	Medical certificate:	Class 1, issued 3 July 1990, valid to 31 July 1991, no limitations
	Instrument rating:	renewed 31 July 1990
	Last base check:	12 July 1990
	Last route check:	23 August 1990
	Flying experience:	total all types: 700 hours total on type: 500 hours total previous 90 days: 57.75 hours total previous 24 hours: 12.6 hours
	Duty time:	5.6 hours
	Rest period before duty:	17.1 hours

1.6 Aircraft information

1.6.1 Leading particulars

Type:	De Havilland Canada DHC-7,Series 110 (also known as Boeing De Havilland DASH 7)
Constructor's number:	110
Date of manufacture:	1988
Certificate of airworthiness:	Transport Category (Passenger)
Total airframe hours:	5,528 hours
Engines:	Four, Pratt & Whitney PT6A-50
Maximum weight authorised for take-off:	19,958 Kg
Actual take-off weight:	17,805 Kg
Estimated weight at time of incident:	17,486 Kg
Estimated fuel remaining at time of incident:	1,542 Kg
Centre of gravity (CG) at time of incident:	33.26% Mean Aerodynamic Chord (within limits)

1.6.2 *History*

The aircraft was constructed in 1988 and completed as a Series 110 (Coincidently, it was aircraft number 110, *ie* the 110th DHC-7 to be built). It was one of a number of DHC-7s originally laid down as series 150 machines which were partly completed at the time continuous production of the DHC-7 finished. It remained at the manufacturer's premises in an incomplete state between 1986 and 1988. It was then completed and delivered as a Series 110 aircraft, the only variant of the DHC-7 certificated by the United Kingdom (UK) Civil Aviation Authority (CAA). Its main differences from earlier Series 110 machines thus lay in the structure, which was designed for the higher gross weight of the 150 Series, and the provision for additional fuel tankage as on the 150 Series which was, however, not fully incorporated. G-BOAW also differed from the majority of DHC-7 aircraft in being equipped with Category II landing minima capability.

All DHC-7 aircraft are designed to be used in a STOL mode utilising a 7.5 degree approach angle as well as the normal 3.5 degree angle used for conventional landings. This enables them to operate from specialised STOL airfields such as London City Airport.

1.6.3 *Flying Controls*

The pitch controls of the DHC-7 aircraft type take the form of elevators driven by spring tabs. The tabs are operated by the control columns via a system of cables and pulleys passing under the cabin floor, through the un-pressurised tailcone and up the vertical stabiliser to the tailplane area (see Appendix A-1).

In accordance with certification requirements, both pitch and roll controls on this aircraft type are capable of being split, *ie* crew selections may be carried out which enable one of the two pilots to control the aircraft in the event of a jam or mechanical restriction occurring somewhere in either the pitch or roll controls.

In the case of pitch control, the two control columns are joined by a cross-shaft incorporating a clutch. Each control column operates an independent system of cables and pulleys. Each of these systems drives a single spring tab attached to one of the two independent elevators. It is thus possible for either pilot to operate one elevator independently through his control column if the clutch on the cross-shaft is first released. This enables flight to continue should one part of the system become jammed (see Appendix A-2).

The pitch trim system takes the form of a trim tab on each elevator surface, both tabs being operated by a single continuous cable loop running from the control console area, under the cabin floor, through the tailcone and up the vertical stabiliser (see Appendix B-1). Rotation of the trim wheels on either side of the control console alters the trim tab angles. A trim position indicator is situated beside the left trim wheel and is driven via a link mechanism from a pin engaging in a spiral groove in the left trim wheel. Part of this mechanism also drives the pitch trim transducer (see Appendix B-2). There is no provision for the pilots to trim the aircraft electrically.

1.6.4 *Automatic Flight Control System (AFCS)*

The aircraft was equipped with a Sperry/Honeywell SPZ 700 AFCS, an integrated Autopilot/Flight Director/Air-data system. Although the basic autopilot system on this Category II machine did not differ from that in the Category I equipped DHC-7 aircraft, some additional installation features were incorporated. The switching arrangements for selection of the autopilot to the Commander's or First Officer's flight system took the form of a caption illuminated pushbutton on the glare shield, in place of a left/right toggle switch in the same position on Category I aircraft. Category II aircraft were equipped with an audio warning of autopilot disconnection, not present on the Category I aircraft.

The SPZ 700 in the DHC-7 operates in all its autopilot pitch modes by way of a servo-drive positioned in the fuselage tailcone aft of the rear pressure bulkhead. The servo-drive incorporates a torque motor and an electromagnetic clutch and is mounted on a bracket which carries a revolving cable-drum. The output shaft from the clutch is splined into the cable-drum. This drum operates a cable-bridle system which applies movement to the cables of the left (commander's) elevator system when the servo-drive causes the drum to rotate. Manual operation of the elevator controls will also cause the bridle to rotate the drum (see Appendix C).

Signals to operate the pitch and roll servo-drives are generated in the autopilot computer situated in the avionics compartment in the nose section of the aircraft, forward of the front cabin pressure bulkhead. In addition to supplying the pitch and roll servo-drives, the computer also supplies signals to the trim motor of the pitch trim system. This is situated below the control console operating through a clutch and sprocket onto a chain forming part of the trim drive cable loop (see Appendix B-2).

Although the pilots have no means of operating the electric trim system, the SPZ 700 does have a TCS facility. This enables pitch and roll attitudes to be altered by pressing the TCS button on the control wheel, establishing the new attitude using the control column, trimming the aircraft manually, and releasing the TCS button. The aircraft will then continue to fly at the new attitude under the control of the autopilot. Whilst the TCS button is depressed the signals from the autopilot computer are interrupted and the clutches in the servo-drives and the trim motor are released.

1.6.5 Maintenance

Although G-BOAW was operated by British Midland Airways, the aircraft maintenance at the time of the incident was entirely the responsibility of another DHC-7 Operator, Brymon Airways.

1.7 Meteorological Information

The Commander reported that the departure conditions at Brussels were, wind 120°/2 kt, visibility 8km in haze, sky clear, temp -1°C , dew point temperature -4°C, QNH 1024 mb. The first officer reported that there was no precipitation.

At the request of the AAIB, The Central Forecasting Division of the Meteorological Office produced a temperature cross-section of the route between Brussels Airport and London City Airport for 1800 hrs on 30 January 1991 (see Appendix D). The history of the ambient temperature which the aircraft would be expected to have encountered was estimated using this information in combination with the height trace from the UFDR. The results are shown at Appendix E.

1.8 Aids to navigation

Not relevant.

1.9 Communications

Communications between the aircraft and air traffic service stations were normal and provided no information relevant to the investigation.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

1.11.1 UFDR

The aircraft was equipped with a Sundstrand UFDR. This recorded a total of 36 parameters plus five discretes (on/off states).

The normal serial format was used and the storage medium was plastic based tape with a duration of 25 hours. A satisfactory replay was carried out using the AAIB's replay facilities. There was no apparent unserviceability in any parameter.

On inspection the pitch trim transducer, which was driven by the handwheel, appeared to be introducing some stiffness into the trim mechanism and so was removed for checking. This unit was of the potentiometer type and tests showed that it was apparently serviceable and was linear over its full range.

1.11.2 Cockpit Voice Recorder (CVR)

The aircraft was fitted with a Fairchild A100 CVR. Due to the duration of the flight after the incident and the length of time that power remained on the aircraft after landing, it had overrun its 30 minute duration and no useful information was recorded.

1.11.3 Data Presentation and Sequence of Events

The longitudinal control and attitude parameters together with airspeed and altitude are shown plotted at Appendix F. Of the two elevators the position of the left hand one only was recorded.

Approximately 14 seconds before the pitch-up on the plot the pitch attitude appears to reduce slightly. The time at which any slow change in pitch started was extremely difficult to estimate as the resolution of the pitch measurements was only 0.35 of a degree. At about the same time there was a small increase in the nose-up elevator demand, from 1 degree up to no more than 1.3 degrees. Six seconds later there was a larger nose-up elevator demand to about 1.6 degrees and the aircraft responded by pitching slowly nose-up. Approximately 3 seconds later the pitch trim increased in a nose-up sense. This was consistent with the normal autopilot operation for an out of limits control force. Over the next 4 seconds the trim increased from its original value of about 5.3 degrees to 8.3 degrees nose-up. During this period the elevator position reduced its nose-up demand slightly but remained largely constant at about 1.5 degrees. The aircraft also appeared to be still pitching up slightly. As the aircraft was approaching 7,800 feet there was a sharp increase in the nose-up elevator demand to just over 3 degrees and the trim movement ceased. The aircraft then pitched up rapidly to about 11 degrees, and the speed decayed as the rate of climb increased. The aircraft then recovered and appeared to climb normally. Throughout the period the autopilot was shown to be engaged, however the TCS position was not recorded.

1.12 Examination of Aircraft and Components

The aircraft was examined by an AAIB Engineering Inspector at London City Airport on the morning of 31 January 1991. The examination concentrated on the pitch control system and was limited by the absence of suitable accommodation and lack of comprehensive ground equipment at this base.

The autopilot computer, the controller, the elevator servo-drive and the pitch trim motor installed at the time of the incident were then taken to the manufacturer's UK Service Centre. On arrival it was established that no facilities were available for testing the trim motor at that facility, the normal practice on receipt of such a component for defect investigation being to forward it to a facility in the USA to enable testing to be carried out.

The remaining three components were subjected to their normal test procedures. The gear case area of the servo-drive was also opened up and the interior examined. Drops of water were noted in the unit and a considerable quantity of the lubricant was discoloured in a way consistent with the effects of water. The electrical connector was found to be badly corroded.

The tests on both the controller and the servo-drive revealed no deviation from the specification performance. The tests on the computer revealed no evidence of any deviations which were judged to be likely to have influenced pitch control under the conditions known to have been present at the time of the incident.

A decision was then taken to ferry the aircraft to the Brymon Airways maintenance facility at Plymouth for a more detailed examination of the controls and the wiring.

On arrival at Plymouth, a replacement pitch trim actuator was installed and connected, all other parts of the autopilot system were re-connected and the autopilot and yaw-damper circuit breakers were reset. Ground tests and functioning of the autopilot system were then carried out in order to confirm the integrity of the autopilot wiring. These revealed no deficiencies in system function.

1.12.1 *Flying controls*

A comprehensive examination of the aircraft pitch control system and the pitch trim system was then carried out involving removal of seats and cabin floor panels together with access panels in the nose area, the tail unit and the control console. In addition the elevators, spring tabs, trim tabs and gust locks were carefully examined.

Particular attention was given to the pulley system area at the rear of the passenger cabin since it was known that leakage of domestic water and/or liquid waste in this area in the past on DHC-7 aircraft had allowed ice to form on the cables and pulleys with consequent restriction of movement of the elevator control system. This area was found to be dry, with no sign of staining and the insulation blankets immediately adjacent to the pulleys were also dry. It was noted that the insulation was in some cases in contact with the control cables but there was no evidence that it had been causing any restriction of movement. No smells of the sort normally associated with liquid leakage were detected.

1.12.2 *Trim System*

Functioning of the elevator trim system revealed a number of areas in the total system travel at which operation was notchy and stiff. Further investigation showed that considerable wear existed on the indicator driving pin which engaged in the spiral groove in the left hand trim wheel. In addition, some slack existed in the chain connecting the trim wheel shaft to the sprocket system in the console and hence to the main trim cable loop. The UFDR trim transducer, which also operates via the pin in the spiral groove was found to have a high level of 'stiction' in its operation.

Replacement of the transducer and cleaning of the trim wheel groove resulted in smooth, progressive movement of the wheel and elimination of the notchy effect.

1.12.3 *Tailplane and elevator de-icing system*

The tailplane and elevator de-icing systems were functionally tested and found to be operating correctly.

1.12.4 *Return to service*

The autopilot servo-drives were disconnected, a replacement pitch trim motor was installed but not connected, the access panels were replaced and the circuit breakers for the autopilot and yaw damper were secured in the open circuit position. The aircraft was subjected to a handling flight test using only manual control. No problems were encountered and it subsequently re-entered service with only manual control available, the yaw damper function being re-instated after consultations between the operator and the CAA.

1.12.5 *Additional Examination and testing*

The aircraft was returned to Plymouth on 9 February 1991 to enable more comprehensive checks on the wiring associated with the autopilot system to be carried out. This work was undertaken in the presence of the AAIB Engineering Inspector under the direction of an avionic specialist from De Havilland Canada using the aircraft manufacturer's design wiring drawings as a reference. In addition to the electrical checks, pull tests were carried out on all relevant junctions between wire terminations and connector blocks to ensure that intermittent contact was not occurring at these points.

With one exception, no defects were found in any of the circuits tested. The exception was a wire found to be not fully engaged in its terminal block. Study of the wiring drawings, however, revealed that the connection formed part of the lift compensation circuit and that any loss of electrical continuity at this point would result in loss of the nose-up signal accompanying the roll command. This would have the practical effect of causing the nose to drop slightly during autopilot turns. Such a defect could have no direct effect on behaviour in pitch modes.

During these checks, the two relays operating the pitch trim motor were removed and functionally tested. They appeared to function correctly. New relays were installed in the aircraft, the flight director computer, left main vertical gyro, vertical accelerometer, and air-data computer were also changed. The aircraft was again returned to service with the autopilot unavailable.

The removed components (with the exception of the accelerometer), were taken to their manufacturer's UK facility for testing. No divergences from specification performance were noted during these tests. Two further programmes of electrical wiring tests relating to the autopilot systems were devised by the electrical and avionic specialists at De Havilland Canada, again using the wiring design drawings as a reference. These were carried out by Brymon Airways electrical engineering personnel at Plymouth during two weekend periods in February and March 1991. No electrical defects were reported as a result of these tests.

After consultation with the avionics specialists at De Havilland Canada, who in turn were in consultation with the autopilot design specialists, it was suggested that the most likely cause of the events portrayed on the UFDR traces was a temporary restriction of movement of the elevator control system or the elevator servo-drive In view of the extensive inspection work already carried out on the flying control system and the continued satisfactory operation of the aircraft in manual control, it was decided to carry out a more detailed examination of the elevator servo-drive.

1.12.6 Component Testing at Manufacturer's Plant

The elevator servo-drive was accordingly transported to its manufacturer's plant at Phoenix, Arizona to enable complete strip examination to take place. The opportunity was also taken to transport the autopilot computer to the facility for a more detailed examination and also to take the trim actuator to the USA since no testing facility existed in the UK.

On arrival, a complete strip examination of the servo-drive was carried out preceded by some special tests. This work centred on the corroded connector and involved introducing substantial quantities of water into the cable terminals at the connector, with electrical power applied, in an attempt to reproduce any short-circuits or false current paths which may have been present during the incident. No such effects were produced and the strip examination did not reveal any defects.

The opportunity was taken to repeat the complete programme of autopilot computer testing using the equipment available. This did not reveal any defects other than those highlighted during the tests conducted at the UK facility. The design expertise available was used to more fully explain the significance of those defects.The defects found in the unit were as follows:-

a. Error in a main power supply voltage level

b. Incorrect airspeed datum at which control sensitivity alters

c. Loss of signal from yaw damper centre of gravity accelerometer.

Whilst at Phoenix it was found that all technical activity with respect to the trim motor was carried at the manufacturer's facility in Wichita, Kansas. The motor was therefore forwarded to that facility for testing which revealed no evidence of any defects within the unit.

1.12.7 Autopilot Pitch Servo-drive drum and bracket

After the completion of the avionic system investigations and the test flight (see Paragraph 1.16.2), a study of the documented history of the problems experienced with pitch control on the DHC-7 type aircraft was carried out. This revealed some ambiguities in the records. Further study and discussions revealed that problems which were recorded as having been encountered with the elevator servo-drive had, in fact, occurred in the drum/bracket assembly. Accordingly arrangements were made to change the drum/bracket assembly in G-BOAW during a brief night stop at London City Airport. The installed unit was removed and transported to the manufacturer's UK facility for strip examination.

The initial examination revealed a 'tide mark' of light corrosion and discolouration in the bracket, indicative of a prolonged period during which a considerable depth of standing water had been present (see Appendix C-1). The greatest depth indicated was such that during acceleration and/or rotation of the aircraft, water would have been able to spill over the end of the bearing area. The strip examination did not reveal any sign of staining within the drum, but both of the shielded bearings showed evidence of slight secretion of lubricant, a feature which, according to the operative involved, is not normally observed during dismantling of drum/bracket units.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

There was no fire.

1.15 Survival Aspects

Not relevant.

1.16 Tests and Research

1.16.1 Tests on the elevator servo-drive drum/bracket assembly

Once the possible significance of the water freezing in the servo-drive drum/bracket became evident, the aircraft manufacturer initiated a test programme to evaluate the effects of such icing. The tests showed that substantial amounts of ice in and around the assembly could resist high operating torques. The full details and results of these tests are reproduced at Appendix G.

1.16.2 Aircraft Flight Test

During the initial part of the investigation, the operator proposed carrying out a test flight of the aircraft with the autopilot in use, making copies of the UFDR results available to the CAA and the AAIB. This proposal was made as part of the process of removing the continuing flight restriction placed on G-BOAW by Emergency Airworthiness Directive (AD) No.013-02-91 *ie* the prohibition on operation with autopilot available (see Paragraph 1.17.2). It was pointed out, however, that the autopilot system had a history of intermittent problems followed, after an interval, by the major event under investigation. It was therefore considered that such a test and UFDR analysis, even if the test flight proved uneventful, would have little effect in providing renewed confidence in the system. It was accordingly decided that any test flight would be delayed until all other aspects of the investigation were complete.

A test flight was therefore carried out on 8 April 1991. The flight took place from London City Airport with a British Midland Airways crew and technical specialists from Brymon Airways, De Havilland Canada and AAIB on board.

The flight involved take-off and initial climb under manual control, with the autopilot first engaged at 1,000 feet. The climb continued to FL200 and all autopilot modes were exercised once in level flight.

A normal descent and coupled approach was carried out with the autopilot being disengaged at 1,000 feet. Flight duration was approximately 1 hour 20 minutes.

1.16.3 Original type testing

Information was sought from De Havilland Canada regarding flight test data on DHC-7 pitch response characteristics.

Tests carried out during development and certification of the type included assessment of aircraft behaviour in autopilot failure conditions. The method of carrying out such flight tests was based on making assumptions of autopilot failure modes. The control surface movements which would result from such modes of failure were recreated by means of special test equipment applying signals to the elevator servo-drive and these movements were followed after a predetermined time interval by pilot recovery action.

The results of the particular test involving weight, CG and airspeed conditions closest to those of the incident flight were examined. The results make it clear that under the conditions present at the time of the incident to G-BOAW, such an autopilot system runaway would be expected to produce a peak normal acceleration (g) increment of approximately 0.5g.

1.17 Additional Information

1.17.1 Aircraft Design Features

A study of the wiring arrangements and autopilot functioning revealed that in a correctly operating system, the audio disconnect warning will sound briefly during normal autopilot disconnection operations. If, however, the autopilot circuit breaker is pulled whilst the autopilot is engaged, the disconnect warning tone will sound continuously, regardless of subsequent autopilot cancellation switching, provided the circuit breaker remains pulled.

The tone may, however, be cancelled by pulling a warning system circuit breaker. Unfortunately, this will also isolate the master caution panel, extinguishing any existing warning indications and preventing any subsequent warnings from showing.

1.17.2 Similar DHC-7 Incident

On 6 February 1991, DHC-7 aircraft G-BRYA, whilst en-route from Lille to London City Airport encountered a pitch control problem which had some apparent similarities to that encountered by G-BOAW. In particular, the behaviour after the autopilot was disengaged suggested to the crew that the elevator servo-drive was not fully declutched. On arrival at London City Airport, a report was made to the CAA, who in view of the preceding incident to G-BOAW, issued Emergency AD No.013-02-91, applicable to all DHC-7 aircraft on the UK register, requiring the autopilot servo-drives to be disconnected and the autopilot circuit breakers to be locked out before further flight. On receipt of information of this further incident, AAIB examined the aircraft at the Brymon Airways base at Plymouth whence the aircraft had been ferried, with autopilot disconnected.

It soon became evident that a major leakage of fluid from the lavatory had occurred and a large block of ice had formed around the cables and pulleys of the elevator control and trim systems. It thus rapidly became clear that this problem was not autopilot related. The work carried out the previous weekend on G-BOAW was done in the knowledge that problems with domestic fluids freezing on flying controls at the rear of the cabin area had happened in the past on DHC-7 aircraft. The absence of any signs of moisture, stains or disagreeable smells in this area on the structure or insulation in G-BOAW made it clear, however, that it did not share G-BRYA's problem. The Emergency AD remained in force until 14 February 1991, when it was removed from all DHC-7s, with the exception of G-BOAW which was not permitted to operate with its autopilot available until the investigative work on the aircraft and autopilot was complete and the test flight had been carried out. This took place successfully on 8 April 1991.

1.17.3 *Previous incidents on a British Registered DHC-7 Aircraft*

During the course of the investigation, a service engineer employed by the autopilot manufacturer recalled that problems with icing in the pitch servo-drive/bracket area had occurred on a Brymon Airways DHC-7 soon after the type was first introduced by that airline. He was subsequently able to find some correspondence made at the time to illustrate the nature of the problem.

This indicated that the aircraft had a history of 'runaway trim' and pitch oscillation in the cruise. It revealed that at about that time a considerable quantity of water was found to have built up in the bracket and ice had formed on the bridle cable such that it fouled the capstan cable keeper posts. Examination at about the same time of another recently delivered aircraft in the fleet revealed that it also had considerable water in its pitch servo-drive bracket.

Proposals were made at the time to introduce drain holes in the bracket. In addition, a series of simple tests were made to establish the routes of ingress of water into the bracket. These showed that water was able to enter via the joint between the servo-drive gearbox and the bracket and that water could enter the servo-drive gearbox via any one of a number of joints in the servo-drive unit.

Subsequently the manufacturer implemented a change to introduce a gasket within the servo-drive to reduce the possibility of water ingress. This change, known as Modification F, was introduced on new servo-drives and on those returned to the manufacturer for repair. The proposed modification to incorporate drain holes in the bracket was not implemented.

It was noted during the investigation into the G-BOAW incident that at least one operator made a practice of applying a strip of sealant around the outside of the joint between the servo-drive unit and the bracket. It is understood that such a strip was in place in G-BOAW at the time of the incident.

1.17.4 *Information from certain US Operators*

A service engineer, who was involved with the testing carried out on the components from G-BOAW taken to the Phoenix facility, subsequently established that a number of North American DHC-7 operators had carried out local modifications to their aircraft. These modifications took the form of shields mounted over the elevator servo-drive drum/bracket assemblies to prevent condensation dripping from the structure onto the units.

1.17.5 *Further Air Safety Action*

On 6 September 1991 De Havilland Canada issued Service Bulletin 7-55-10 recommending that modification number 7/2605 be accomplished within 500 flight hours of the issue date. The modification calls for a water deflector to be installed on the front spar of the vertical stabilizer directly above the elevator servo-drive to prevent water ingress. On 30 September 1991 the UK CAA stated in a communication to the AAIB that they were progressing a proposal for mandatory classification for this Service Bulletin.

1.18 New investigation techniques

No new techniques were employed.

2 Analysis

2.1 General

The commander and first officer, having experienced a dramatic uncommanded pitch-up early in the flight continued to experience unusual control feel in pitch and perceived a further pitch excursion when flap was selected for the landing at London City Airport. Having consequently decided that a flapless landing was called for, it was necessary to divert from the intended STOL destination and Stansted Airport offered a runway of suitable length for such a flapless approach and landing.

The recollection of the crew as to both the forecast and actual weather conditions throughout the flight leads to the conclusion that airframe icing did not play any part in the problems encountered. The information provided subsequently by the Meteorological Office also indicates that the initial part, before the pitch-up, and most of the remainder of the flight must have been conducted in clear air, free from conditions which could lead to significant airframe icing.

Examination and testing of the electronic components of the AFCS revealed no evidence of any defect which could have caused major pitch excursions. It also proved possible with the aid of the design expertise at the manufacturer's facility to confirm the initial view that the problems found in the autopilot computer could not have affected the pitch behaviour of the system. The problems found would have had the following effects:-

a. The incorrect power supply voltage had no effect on the behaviour of the computer other than being the possible cause of item b. below.

b. The error in airspeed datum at which the system sensitivity altered would not have affected the aircraft at the time of the pitch-up incident. This change-over airspeed is normally considerably lower than the airspeed of the aircraft at the time of the incident and remained below that speed even in the presence of the defect found on test. The airspeed at the time of the incident thus remained in the correct sensitivity range. It is also unlikely that the datum change would have had any noticeable effect on the aircraft's general flight behaviour.

c. The loss of signal from the yaw axis centre of gravity accelerometer would result in operation of the yaw damper during any lateral translational acceleration of the aircraft, in addition to its normal modes of operation. It is unlikely that this defect would be particularly noticeable in normal flight, and it could not influence pitch behaviour.

The possible loss of lift compensation signal resulting from the aircraft wiring problem identified during tests at Plymouth would merely result in a slight tendency for the aircraft to descend during turns should a loss of electrical continuity actually occur.

2.2 Analysis of UFDR Data

The UFDR showed that in the cruise the autopilot was engaged and disengaged several times, being engaged for periods of between 1 and 4 minutes duration. The periods of disengagement were rather longer. Although the flight was conducted in smooth air at the cruising level, the variations of elevator angle and pitch attitude were about twice as large as those shown on earlier flights, and these variations also showed up on the g trace, which showed vertical accelerations between 0.91g and 1.09g, typical of flight in light turbulence. These fluctuations showed whether the aircraft was under autopilot or manual control but tended to be of slightly lower amplitude when the autopilot was engaged.

Just before the pitch-up, movement of the elevator in an aircraft nose-up sense can be seen to occur over a period of approximately 2 seconds. It then ceases and approximately a further 2 seconds later the trim system begins to operate, in the same sense. Electric operation of pitch trim can only take place once the elevator servo-drive has been drawing a signal above a specified threshold level for more than 3 seconds. The period between the initial movement of the elevator and the onset of trim movement is between 3 and 4 seconds, suggesting that the elevator servo-drive signal passed that threshold soon after elevator movement began.

The cessation of elevator movement followed by the beginning of trim movement indicates that a signal above the trim actuation threshold was being supplied to the elevator servo-drive for the 3 seconds preceding the start of the trim movement, but the elevator only responded to this signal for the initial 1 second of the period. The only way this could occur (without any failure being present in the computer or the wiring) was for a restriction in the elevator control circuit to have been present. This would have caused the autopilot computer to continue to supply an aircraft nose-up signal to the elevator servo-drive, which, being restricted in its movement, would fail to correct the aircraft pitch error and thus continue to receive the nose-up signal.

Trim tab movement should naturally result in a change of elevator angle provided that the elevator operating circuit is unrestricted. The recording of elevator position on the UFDR, however, shows only a small change during the period of the trim movement. This period of movement totals 4 to 5 seconds and during the final part of the movement there are signs of slight elevator displacement in the aircraft nose-up sense, giving about 2 seconds of recorded trim movement without any significant corresponding elevator angle change in the aircraft nose-up sense.

The design of the elevator control system of the DHC-7 is such that if movement of the elevator surface were to occur with its operating circuit locked, deflection of the spring tab would occur in the same direction as the elevator movement. Thus, with cables locked, any movement of the elevator surface under the influence of the trim tab would be resisted by deflection of the spring tab in an 'anti-balance' sense and hence only a very small elevator deflection would actually occur.

Theoretical figures supplied by the manufacturer show that, in such a condition, the ratio of elevator movement to trim tab movement is of the order of 0.24 at the speed in question. Thus, with the total recorded trim movement of approximately 3 degrees, a corresponding total elevator movement of slightly less than 1 degree would be expected.

The UFDR traces show that over a period of some 4 to 5 seconds during which trim system movement is recorded, the elevator position varied slightly but did not undergo significant net change. During the final 2 seconds of recorded trim movement, however, the elevator trace shows approximitely 0.2 degrees movement in the aircraft nose-up sense, *ie* in the direction corresponding to the trim movement. The recorded trim tab movement over this 2 second period is approximately 1 degree. Thus the ratio of recorded elevator movement to recorded trim tab deflection during the final 2 seconds of trim tab movement is 0.2. This figure agrees closely with the theoretical figure of 0.24 mentioned above.

Clearly, the initial 2 seconds of recorded trim tab movement is not accompanied by appropriate recorded elevator response. This may be due to the fact that the trim tab mounted on the transducer equipped elevator was not actually moving significantly during the first 2 seconds of recorded trim movement.

This possible discrepancy between actual and recorded trim tab movement may be explained as follows:-

The trim position potentiometer is situated within the control console on the flight deck, close to the trim motor (see Appendix B). The two tabs are each driven via a continuous loop of cables and chains running the length of the aircraft, up the vertical stabiliser and out into both elevators. It is thus reasonable to suppose that less backlash or lost motion existed in the drive between the motor and the transducer than in the total drive between the motor and the left elevator (each elevator has its own trim tab and only the left elevator carries a position transducer).

Thus although the trim system is recorded as being in motion over a 4 to 5 second period, one trim tab may not have started to deflect until the middle of this period resulting in a false impression of a lack of appropriate elevator response.

Additionally it should be born in mind that the small angular changes under consideration are close to the limits of the capabilities of the recording system.

Thus, although the recorded elevator movement is considerably less than might be expected, this figure is probably influenced by the limitations of the recording equipment and the design of the trim system.

2.2.1 *Aircraft pitch response*

The recorder shows a nose-up pitch and consequent g response to the sudden up elevator movement at the time of the initial incident. The g value recorded at this point rises rapidly to a peak of 1.8g, *ie* an increment of 0.8g.

The Flight Test information supplied by De Havilland Canada (see Paragraph 1.16.2) makes it clear that under the flight conditions present at the time of the incident to G-BOAW, an autopilot system runaway would produce a peak increment of approximately 0.5g. This figure was arrived at by carrying out development testing making certain assumptions about autopilot and pilot behaviour.

There is clearly a considerable difference between the situation assumed for the flight tests and that which would occur in the circumstances of temporary control system restriction. The latter could result in a high servo-drive torque being developed with no corresponding control movement before the restriction suddenly released, allowing the servo-drive to drive the elevator bridle and thus create an immediate high rate of elevator spring tab movement. It is therefore reasonable to expect that under these conditions a more rapid and larger tab movement would occur, before pilot intervention, than that achieved in the development flight tests. It is therefore consistent that a g figure of 1.8 (0.8 increment), might occur after the restriction cleared, rather than the lower figure produced in flight tests carried out under similar conditions of weight, CG position and airspeed.

2.3 Possible Sources of Control Restriction

The water found to be present in the gear-case area of the pitch servo-drive, together with the greater quantity which appears to have been there in the past, given the discolouration of the lubricant, is a possible source of control restriction. During operation at the low temperatures encountered in flight, freezing of this water could have had the effect of preventing the servo-drive from responding to signals until a high, sustained signal was developed. Unless, however, water entered and froze in the clutch housing, thereby preventing clutch release, this problem would have ceased to affect the flying controls as soon as the autopilot was disengaged. This would not, therefore, explain any of the problems experienced by the crew during the latter part of the flight when the aircraft was being flown manually. If, however, ice formed in and/or around the autopilot cable-drum, then a control restriction would be present when the aircraft operated in either manual or automatic flight.

It is evident that when in manual flight the commander was experiencing some difference in the 'feel' and/or response characteristics of the aircraft from that which he regarded as normal. Despite the apparent differences between his report of aircraft behaviour and some of the features noted on the UFDR, there can be little doubt that some continuing problem was present in pitch control. These handling problems resulted in him declaring an emergency, diverting to Stansted and landing flapless.

A very comprehensive examination of the control system after the incident revealed no evidence of any mechanical problem. In addition operation of the aircraft since the incident has continued with no difficulties. No evidence of the problem which afflicted G-BRYA was present in G-BOAW. There is no reason to believe that tailplane/elevator ice was present at the time of the pitch-up and thereafter the tailplane and elevator de-ice systems were used. There is no evidence that serious airframe icing conditions were encountered anywhere in the flight and testing of the de-icing systems carried out at Plymouth shortly after the incident showed them to be operating correctly.

Examination of the elevator servo-drive drum/bracket assembly carried out some considerable time after the incident revealed the presence of a 'tide' mark in the bracket indicative of a substantial quantity of water having been present there for a considerable period at some time in the past.

2.4 Temperatures in the Tailcone

The temperature/time history of the flight (see Appendix E) shows that the aircraft was subjected to a period of approximately 1 hour, ending shortly before the pitch-up incident, during which the ambient temperature was just above 0°C. Throughout most of the previous hour it remained below 0°C, dropping to -17°C for a large part of the period.

The elevator servo-drive bracket is attached directly to the forward spar of the vertical stabiliser, close to the bottom of the tailcone. In this position it will suffer temperature hysteresis, the skins of the stabiliser being influenced directly by ambient temperature, whilst the lower end of the vertical stabiliser spar will cool progressively towards the ambient temperature after a significant time delay. During the period on the ground the structure of the vertical stabiliser would have acted as a heat-sink, causing the lower section of the spar to continue cooling. The period on the ground in this case was only about 1 hour, at between -1°C and +1°C ambient temperature, so it is probable that the lower end of the spar continued to cool throughout this time. It is most unlikely that the drum/bracket assembly rose to a temperature above freezing whilst on the ground or during the initial climb.

2.5 Effects of ice on the Drum/Bracket Assembly

2.5.1 Manufacturer's tests

The tests carried out by De Havilland Canada on the effects of ice formation in and around the drum (see Appendix G) confirm that substantial servo-drive torques can be resisted in this condition. It is thus reasonable to suppose that a control restriction due to the presence of ice in and around the drum was the cause of the initial restriction, and its sudden release under load caused the rapid elevator movement which produced the pitch-up effect. Some continuation of this restriction after reversion to manual flight would explain the commander's continued experience of abnormal feel and his anxiety over pitch control.

2.5.2 Effect of ice restriction on manual control behaviour

The precise effect of ice restriction whilst in manual flight is hard to quantify, but the system might be expected to perform initially as though a stiff spring existed between the control column and the servo-drive drum (*ie* The effect of approximately 50 feet of the left elevator cables and autopilot bridle suffering slight elastic deformation under tensile load as the commander applied control column forces reacted at the frozen drum).

Sustained elevator control force applied by the commander with the servo-drive drum restricted or locked by icing would result in a steady torque being applied to the drum, the resulting elastic tensile deformation of the left elevator control cable and autopilot bridle permitting a small control column movement. A corresponding deflection of the right elevator would be achieved by virtue of the separate elevator cable system on the right side of the aircraft. If the drum then 'slipped', the released strain energy of the left cable would rotate the drum and cause a sudden deflection of the left elevator. At the same time, resistance to the the sustained pilot control force would reduce and column movement result until a significant further deflection of both spring tabs and hence both elevator surfaces had been achieved and increased aerodynamic feel force encountered. This would obviously be accompanied by a further pitch change.

This abnormal resistance of the control column to applied control forces, followed by a sudden reduction in that resistance, could lead to inadvertant and, to the crew, inexplicable overcontrolling. Such erratic control response would serve to confuse and alarm them. If active manual trim wheel movement was also being carried out to assist accurate pitch control, this effect would be accentuated, since trimming would be taking place to overcome a mechanically induced stick force, rather than an aerodynamic force. Such movement of the trim wheel would actually place the aircraft out of trim, leading, when any slippage of the drum occurred, to greater pitch changes and greater control column movements than would have happened with unaided elevator movement.

2.5.3 *Effect of ice restriction on Controls before the Pitch-up Event*

Although the pre-take-off 'full-and-free' checks, together with the elevator movement at rotation, might have been expected to reveal some signs of a pitch control restriction were icing to be present in the servo-drive drum, the movements in both cases are normally fairly coarse, using both hands and considerable force. These are less likely to reveal a subtle control restriction than the requirement to maintain accurate height control manually in the cruise with the same servo-drive drum restriction present. The control column forces normally used in rotation and in full-and-free checks are capable of producing a considerably higher torque at the drum than the maximum capable of being produced by the servo-drive. It is therefore reasonable to suppose that a level of resistance to elevator movement, sufficient to precipitate the pitch-up phenomenon which occurred, could have been present during the pre-flight activities and take-off, without being evident to the crew.

2.6 Previous Incidents

The earlier difficulties encountered on a DHC-7 (see Paragraph 1.17.3) illustrate that pitch control problems, albeit of a somewhat different nature from that experienced by G-BOAW, have previously resulted from ice formation in and around the servo-drive bracket of this aircraft type. It is reasonable to assume that those runaway trim movements and pitch oscillations resulted from operation of the trim motor after signals to the elevator servo-drive failed to achieve any control movement. The sustained elevator servo-drive signal is then presumed to have resulted in a delayed operating signal being supplied to the trim motor. Hence a delayed and out of phase pitch correction would have been applied via the trim system resulting in aircraft pitch oscillation.

In addition, the discovery that a number of DHC-7 operators in North America have unilaterally fitted covers to prevent condensation from falling onto the elevator servo-drive/bracket assemblies from the inside of the tailcone structure suggests that problems in this area are widespread. It is unfortunate that the possible consequences of the problem have gone largely unrecognised and no concerted action was taken until recently to correct the problem.

It is recommended that the CAA make the De Havilland Canada service bulletin 7-55-10 mandatory and that the CAA and the manufacturer take steps to ensure that provision for drainage of the elevator servo-drive drum bracket is incorporated in DHC-7 aircraft.

2.7 Effect of Splitting the Pitch Controls

A control restriction resulting from ice on the cable-drum assembly would continue to affect the commander's section of the controls after the pitch system interconnect was disengaged, since the cable-drum operates directly on the commander's control cables. The greater angular control surface movement then required to achieve a particular pitch response would produce more rotational movement of the cable-drum with the controls split than with them operating in their normal mode. The effect of such movement with friction and stiction generated by an ice affected drum, on the commander's perception of control feel, is difficult to quantify. It is, however, entirely reasonable to accept that he would consider a control problem still to be present.

The first officer recalled that, with the controls split, he required larger inputs for control of the aircraft in pitch than would be expected and his perception was that the movements were larger than he had witnessed in training. Large movements are to be expected given that splitting of the controls provides each pilot with control of only one elevator rather than the two elevators used when in the normal mode. Flight with controls split is only demonstrated briefly during training. This is in a relatively unstressed environment, using a limited part of the flight envelope. It is understood that the exercise is usually carried out at an airspeed of about 140 kt, whereas the area on the UFDR recording at which the control disconnection is believed to have been made indicates an airspeed of approximately 180 kt. It is questionable if a first officer is exposed to sufficient operation with controls split during initial type training to be able to make a realistic comparison at a later date under significantly different physical and psychological conditions. It is also not clear if a fully serviceable aircraft operating with controls split, when flown from the first officer's seat, would feel and behave in the same way as one operating under the same conditions but having some physical restriction to the 'stick-free' movement or float of the other, non operating elevator tab as would have been the case with G-BOAW. The first officer's perceptions are therefore not necessarily inconsistent with the aircraft response likely to result from a restricted elevator servo-drive drum.

2.8 Commander's Perception of Manual Trim Operation

The Captain reported that towards the end of the flight he considered the trim to have been stiff in operation. During the examination of the aircraft at Plymouth shortly after the event it was noted that motion of the trim was notchy and it had a region of stiff operation. This was rectified before re-entry into service by cleaning the spiral groove which accommodates the driving pin and replacing the trim position transducer. Unfortunately, the position in the range of trim movement at which the stiffest operation occurred was not noted. A study of the UFDR trim trace, however, shows that the trim position reaches its most nose-up of any stage in the manual part of the flight shortly before the landing. This is thus a stage in the flight at which the trim reaches a position range not hitherto entered in manual control during the flight. It seems likely that the nose-up region was the part of the range at which the stiff notchy motion was most pronounced and that this was the origin of the problem that the commander identified at the end of the flight.

2.9 Pitch-Down During Flap Extension

Although the crew were very conscious of a large pitch change just after flap was selected, there is no evidence on the UFDR that this occurred. It is quite possible, however, for a handling pilot in a high work-load situation to perceive or remember a high control force not as such, but as a large attitude change, even though the control force was successfully resisted and little attitude change actually took place. It is thus worth noting that immediately before the flap operation began there was a progressive nose-down pitch change of approximately 3 degrees building up over a period of approximately 1 minute. This started just after the autopilot was disengaged for the last time, the time at which the highly distracting continuous autopilot disconnect warning presumably began to sound.

This pitch change appears to have been countered by an increasing, although small, up-elevator input culminating in two (presumably manual) nose-up pitch trim inputs, the larger occurring as the flap movement began. The operation of the trim certainly suggests that the handling pilot became aware at this stage that he was having to hold a significant back-stick force to maintain his desired flightpath or attitude. The commander could therefore well have been left with the recollection of a large nose-down pitch change rather than the nose-down trim change that he appears to have experienced.

The period from shortly after autopilot disconnection to shortly before initial flap movement was occupied by a considerable deceleration of the aircraft, apparently as a result of a major power reduction. It is a well known phenomenon that longitudinal accelerations give the perception of a false horizon to a subject who has no visual reference. Although this event occurred in conditions of good visibility, the deceleration may nonetheless have contributed to a feeling or recollection of being more nose-down than was actually the case. This effect, if present, could have been experienced by both crew members. It is very possible that the continuous autopilot warning which began at this time contributed to a certain amount of crew distraction leading to confused perception and/or inaccurate recollection.

2.10 Continuous Autopilot Disconnect Warning

The commander stated that he was seriously inconvenienced by the continuous sound of the autopilot disconnect warning after the first officer operated the autopilot circuit breakers. A study of the wiring logic shows that such continuous operation will not occur in a correctly operating system provided the autopilot is disconnected by one of the normal methods before the circuit breakers are pulled. The crew, however, are understood to have interpreted the symptoms of their control problem as being a possible failure of their autopilot to disconnect correctly. It would not therefore be surprising if, after selecting and de-selecting the autopilot a number times they pulled the breakers when the autopilot was actually engaged. Thereafter, the only courses open to them to silence the warning were:-

a. Reset the circuit breakers, de-select the autopilot and pull the circuit breakers.

b. Locate and pull the circuit breaker controlling the warning system, thereby having the undesirable effect of also extinguishing the central warning panel/master caution panel.

Obviously the first course of action would have been preferable. Both courses would, however, have been difficult to achieve given the problems of crew communication with the continuous distraction of the warning system and the generally high work-load at that stage in the flight. The surprisingly large number of circuit breakers in this aircraft would complicate the task. It is not reasonable to expect crew members to have sufficiently detailed knowledge of the logic of the warning system to be able to silence it in these circumstances without reference to the flight manual and it would be difficult to draft a flight manual capable of rapidly leading a crew to the solution of this problem.

It is most undesirable to have any audio warning on a flight-deck which can continue to sound after its value as a warning has ceased; a continuous warning of autopilot disengagement also serves no useful purpose. It is therefore important to eliminate the possibility of this occurring by hardware design rather than by emphasis on correct procedures. Such an inappropriate prolonged warning occurring at a time of high work-load and anxiety created an unacceptable additional distraction.

It is recommended that:-

a. The CAA liaise with the manufacturers of the DHC-7 to introduce a modification to ensure that audio autopilot disconnect warnings, when fitted, are unable to operate continuously, regardless of the cause of initial operation.

b. The CAA and other authorities examine other autopilot equipped aircraft on the registers to identify those which may suffer from analogous problems with tailcone mounted servo-drives and with audio warnings, and take steps to ensure that the risk of such problems occurring is eliminated.

3 Conclusions

(a) Findings

(i) The crew were properly licenced, medically fit and sufficiently rested to operate the flight.

(ii) The aircraft suffered an uncommanded pitch-up during the climb with the AFCS operating in the Vertical Speed Mode.

(iii) A brief period of elevator control system restriction probably occurred before the pitch-up.

(iv) During this period the autopilot computer apparently signalled a nose-up elevator movement without achieving a corresponding aircraft pitch change.

(v) The control restriction is thought to have resulted in a high torque being developed and sustained by the elevator servo-drive which in turn caused the autopilot computer to supply a nose-up signal to the trim motor.

(vi) Shortly after the trim system began moving, the elevator control restriction appears to have released causing the sustained servo-drive torque to drive the elevator spring tabs and hence the elevators rapidly in a pitch-up sense.

(vii) At a later stage in the flight , the crew experienced control difficulties in manual flight.

(viii) Having experienced a dramatic, uncommanded pitch-up followed by unusual pitch control feel in manual flight the crew perceived further handling problems associated with the deployment of flap. As a consequence, they prudently elected to divert from their planned STOL destination to a conventional airfield where they could make a flapless approach and landing.

(ix) The problems experienced in both automatic and manual flight were almost certainly caused by freezing of water which had collected in the bracket of the elevator servo-drive drum and possibly on the bridle, as a result of condensation dripping onto the assembly from the tailcone structure over a prolonged period.

(x) The ice continued to effect the drum causing unfamiliar feel and/or response characteristics later when the crew operated the aircraft in manual control.

(xi) The problems of the crew were compounded towards the end of the flight by the continuous operation of the autopilot disconnect warning.

(b) Causal factors

(i) Condensation was able to collect in and around the elevator servo-drive drum bracket and freeze causing an elevator control restriction which affected pitch control in both automatic and manual controlled flight.

(ii) Following earlier known cases of water collecting in and around the elevator servo-drive drum bracket no effective modification action was implemented.

(iii) The flight deck crew's ability to discuss and analyse their predicament was impaired by the distraction provided by the continuous operation of the autopilot disconnect warning.

4 Safety Recommendations

It is recommended that:-

4.1 The CAA make the De Havilland Canada service bulletin 7-55-10 mandatory.

4.2 The CAA and the manufacturer take steps to ensure that provision for drainage of the elevator servo-drive drum bracket is incorporated in DHC-7 aircraft.

4.3 The CAA liaise with the manufacturers of the DHC-7 to introduce a modification to ensure that audio autopilot disconnect warnings, when fitted, are unable to operate continuously, regardless of the cause of initial operation.

4.4 The CAA and other authorities examine other autopilot equipped aircraft on the registers to identify those which may suffer from analogous problems with tailcone mounted servo-drives and with audio warnings, and take steps to ensure that the risk of such problems occurring is eliminated.

D F KING
Inspector of Air Accidents
Air Accidents Investigation Branch
Department of Transport

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The Civil Aviation Authority's response to these Safety Recommendations is contained in CAA Follow-up on Accident Reports (FACTAR) No. 3/92, to be published coincident with this report.